JOURNAL

OF THE

WASHINGTON ACADEMY OF SCIENCES

VOL. 20 JUNE 4, 1930 NO. 11

PHYSICAL GEOGRAPHY.—*Peat profiles in the Puget Sound Basin of Washington.*[1] ALFRED P. DACHNOWSKI-STOKES, U. S. Bureau of Chemistry and Soils.

I.

The purpose of the present paper is to set forth the relationship between peat materials, profile features, and certain events recorded in peatlands of the Puget Sound Basin. The desire to study further the evidence of recent changes of sea level observed in the Delta peatlands of California (6) led to a continuation of field work in Washington, with the view to compare and if possible to connect it with the evidence obtained from peat deposits in Florida (4), North Carolina (3) and Maine (5). This paper is chiefly an account of the order of occurrence of the different layers of peat in profile sections because a record of this kind enables coördination between peatlands and represents also the history of the succession of past vegetation and of the former conditions of the region, in part very unlike those now existing. A general description of the present vegetation of these areas, as well as their environmental conditions is to be published elsewhere in this journal by Rigg.[2] The agricultural practices and purposes and the economic aspects of the different types of moors studied it is hoped to set forth in another paper.

The geologic history of the Puget Sound Basin has been reported by several writers (1, 7, 14) and is summarized in the Tacoma folio No. 54 of the Geologic Atlas of the United States (15). Puget Sound occupies

[1] Received April 23, 1930.

[2] The soundings and general examination of most of the peat areas were carried out together with Prof. G. B. RIGG of the Department of Botany, University of Washington, Seattle, and with Messrs. C. H. BERGSTROM and C. W. NORTON of the County Extension Service. The author takes this opportunity to express his appreciation and indebtedness for the coöperation and helpful assistance rendered.

an ancient depression parallel to the Pacific coast. Mountain ranges lie on either side of the trough-like depression, the Olympic Mountains on the west and the high Cascade Mountains on the east.

The geography and the soils of this region have been described in a reconnaissance soil survey made by Mangum (8). The principal topographic features are peculiar in that they fall naturally into two distinct sections. The major depressions consist partly of a branching system of land-locked, narrow lakes and sounds and partly of valleys of the larger streams, flowing in ill-defined channels and emptying into Puget Sound. The elevations are ridges of the plateau type, essentially flat topped, bounded by rather steep slopes, and standing out as islands and peninsulas with the long axis trending north and south. Lakes occupy many depressions upon the plateaus. It is probable that the principal topographic features conform to an older topographic relief and are a part of the sequence of events which developed during the Glacial period. Willis and Smith (15) state that along many stretches of Admiralty Inlet in the Puget Sound "there is a terrace about 20 feet above the present sea level. In some places it appears to be a wave-cut bank; and elsewhere it is a delta terrace built out by a tributary system. This 20 foot terrace probably represents an earlier relation to the sea level, when it stood 20 feet higher against the land than it now stands. Other benches have been observed varying from 60 to 100 feet above sea level." Interpreting a group of facts Willis and Smith infer that since the last Glacial period the land stood high enough above sea to permit rivers to cut as deeply as the bottom of the sound, and that the land has subsided, submerging the valleys to the present depth. According to Kimball (7) the post-glacial crustal movements have been an elevation and a subsidence followed by a more recent re-elevation.

The nearness of the high mountains condensing the moisture of the prevailing western winds, and the warm Japan ocean current of the northeastern Pacific are the chief factors which profoundly affect the climate of this region. Although Puget Sound lies in the latitude of Newfoundland, it has been described as having a mean temperature which corresponds to a latitude like that of Chesapeake Bay on the Atlantic Coast. The rainfall varies but the averages range probably from 40 to 55 inches per annum. The precipitation is distributed throughout a mild, rainy winter season, with a cool summer of little rainfall. As a result of the equable, maritime climate many plants which normally inhabit cold or humid and even arid climates have migrated into the Puget Sound Basin. A northern vegetation merges by a narrow transition belt into the southern zone of plant life and con-

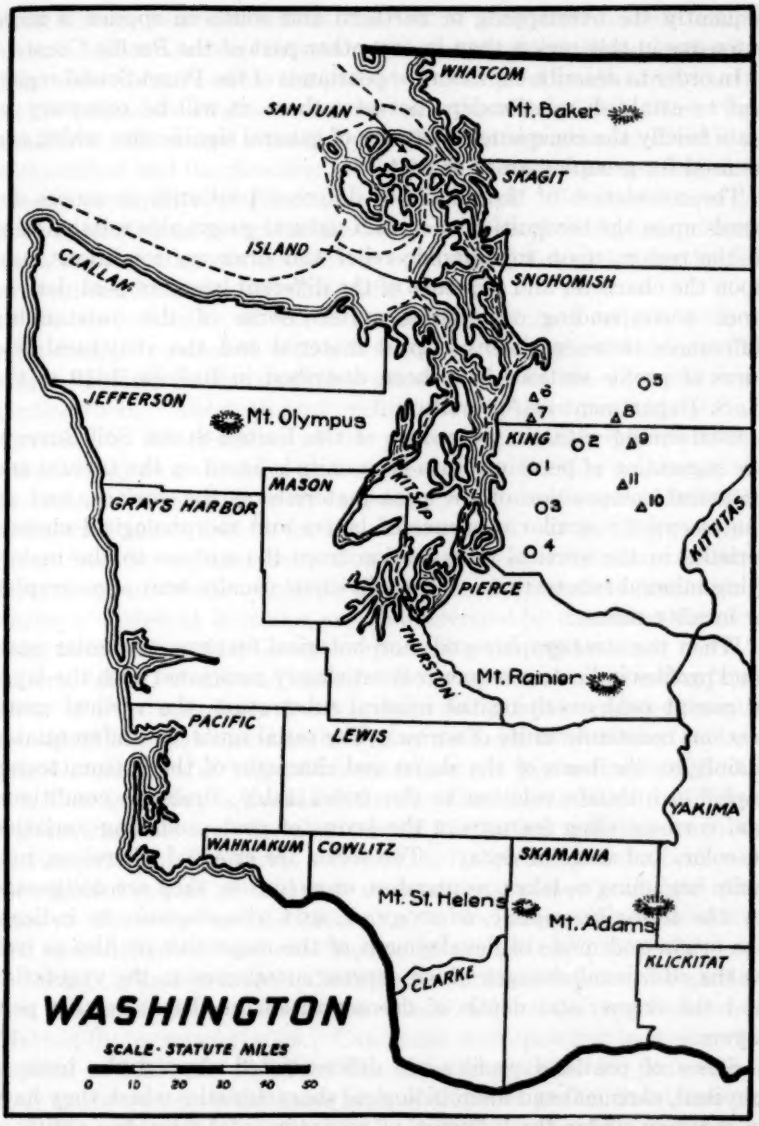


Fig. 1.—Map showing the location and numbers of peat-profile soundings in the Puget Sound Basin of eastern Washington and the principal volcanic peaks that are now extinct.

sequently the overlapping of northern and southern species is more extensive in this region than in any other part of the Pacific Coast.

In order to describe the moors or peatlands of the Puget Sound region and to establish relationships between them, it will be necessary to state briefly the conspicuous features of general significance which can be used for grouping areas of peat.

The correlation of the details of different peatlands or moors depends upon the recognition of certain natural geographic relationships of the region, upon topographic relief and drainage conditions, and upon the character and sequence of the different layers of peat derived from corresponding vegetation units. Some of the outstanding differences between classes of peat material and the structural features of profile sections have been described in Bulletin 1419 of the U. S. Department of Agriculture.

Conforming with the procedure of the United States Soil Survey, the separation of peatlands into type units is based on the texture and botanical composition of the peat materials at the surface, and on the essentially similar sequence of layers and morphological characteristics in the vertical cross-section from the surface to the underlying mineral substratum. These divisions usually bear a geographic or locality name.

When the stratigraphic and morphological features of similar peatland profiles indicate a sequence most closely associated with the layer of parent peat overlying the mineral substratum, the vertical cross-sections constitute units of series. The serial units are differentiated mainly on the basis of the shape and character of the bottom topography in intimate relation to the water table, drainage conditions, and corresponding features in the layers of peat producing variation in color, and stage of decay. The series are grouped, therefore, into units beginning as lakes, as marshes, or as forests; they are designated by the terms *limnogenic*, *telmatogenic*, and *terrestrogenic*, to indicate the origin and mode of development of the respective profiles as well as the additional changes which express successions in the vegetation and the degree and depth of decomposition of the respective peat layers.

Series of peatland profiles are differentiated also on the basis of physical, chemical and microbiological characteristics which they have in common under the influence of environmental processes active in different regions and climates. The concentrating effect of evaporation in arid climates, the diluting and leaching effect of rainfall in humid regions, often completely removing certain constituents from the surface of the profile, the solutes contributed with ground- and

flood-waters, very different in their saline composition from tellurial waters, lead to characteristics that can be given a regional expression. The wide range in cold, temperate, and tropical environment under which peatlands originate and become transformed from the virgin condition; the stages marked by profile features associated with decomposition and the direction in which the process is proceeding, these require recognition of geographic relationships. No names have yet been suggested to designate the characteristics of this group of serial units because they are not clearly enough defined, owing to the lack of accumulated facts regarding them.

The several units of moors are further grouped on the basis of relationships associated with differences in the regions dominated by major divisions of the natural vegetation and by the peat soils supporting them. Although peat profiles show in their past history much variation in the character of the plant communities that were supported from time to time and succeeded one another as stages, yet the natural vegetative cover is generally the expression of interrelations with many factors in the environment. It provides often a better basis for regional distinctions between moors than any one set of factors and processes. In their present development the peatlands or moors of different latitudes are characterized by dominant forms of vegetation units, vast in extent and of great permanence, such as tundra, forest, shrub, and marsh. However the corresponding larger units of peat soils have not yet been defined or correlated because ecological and pedomorphic data have not been fully worked out and suitable concepts of vegetation units are not yet well established.

A final grouping is based on the reaction of peatlands in different regions, regardless of the character of the parent peat layers in the profile section. The terms *eutrophic* and *oligotrophic* have been used for regional groups of moors to designate more specifically the presence or absence of certain mineral salts, including carbonate of lime and essential plant food constituents in the peat soil solution.

Enough is known to indicate that a preliminary scheme of classification can be used for moors or peatlands such as that worked out by Marbut (9) for mineral soils. Categories corresponding in their major aspects to Marbut's divisions should be practicable for peat soils if they are accepted on the same basis of inherent profile characteristics and general environmental relationships. Regional investigations along these lines are being continued.[3]

[3] For a map showing regions in which the major groups of peatland occur in the United States, see Journ. Amer. Soc. Agronomy **22**: *352–366*. 1930.

With this viewpoint in mind the peatlands in the Puget Sound Basin may be described separately as follows:

II

PROFILES OF PEATLANDS IN THE VALLEY FLOOR

A number of lakes lie scattered over the valley floor, of which the largest are Lake Washington and Sammamish Lake, occupying elevations of 22 and 35 feet above sea level respectively. Lingering tongues of stagnant Vashon ice probably occupied hollows or valleys of earlier origin. Subsequent melting of the buried ice left the depressions occupied by water which was later ponded by alluvial deposits of drift. Streams and tributaries flow into the lakes, forming a connected drainage system which empties into the Puget Sound.

The water supplies from the Duwamish, Puyallup, and Snohomish Rivers reported by Byers carry only a small amount of mineral matter in solution (2). Van Winkle (14) states in his account of the average chemical composition of the river waters, that "all the waters belong to the calcium carbonate type,—that is, the alkaline earths calcium and magnesium, and carbonates or bicarbonates predominate. The content of sulphate is not large and chlorine is very low. Silica, though not present in very great quantity, consitutes a large proportion of the mineral matter in such dilute solutions. Iron is generally so low as to be almost inappreciable."

Fine silt from the glaciers of Mount Rainier is occasionally laid down close to the main river channels. By this means natural dikes are being built up which in places are bordered by bodies of quiet water, swamp and marsh. Large areas of the valley floor are subject to inundation by spring and autumn rains. Although the water carries salts in solution which serve as plant food constituents, the river beds being higher than the plain present problems of flood control.

The primeval vegetation in the valleys was a forest of cedar (*Thuja plicata*), white fir (*Abies grandis*) and deciduous shrubs such as alder, willow, maple and other associates. The wetter ground was inhabited by extensive marshes resembling the "tule" land of southern Oregon and California. They are of rather uniform floristic character in which reeds, tule, cat-tail, sedges, buckbean, arrow grass, burr reed, marshlocks and aquatic plants form the chief components.

The peat soils at the surface may have a loose, gray brown mulch but the subsurface material varies in texture from a woody-fibrous sedge peat or a light-brown, coarse, fibrous-matted to a heavier type of sedimentary-fibrous sedge and reed peat which contains a high

percentage of diatomaceous earth and silt at a shallow depth below the surface. Truck gardening has become the important type of peatland agriculture. Most of the valley land between Seattle and Tacoma, including large areas of peat, is now generally cleared, improved, and traversed by railroads.

1. The Mercer Slough type profile

About 7 miles east of Seattle, on the eastern shore of Lake Washington, is Mercer Slough. The form and area of the peat deposit are shown on the Seattle topographic sheet of the United States Geological Survey. It lies in T. 24 N., R. 5 E., along sections, 5, 8, and 17, and is reached from Seattle by a circuitous road around the northern end of Lake Washington. The peat deposit is a grass-sedge lowmoor and occupies a flat but gently sloping depression, limited by relatively steep banks. It is about half a mile wide and contains a finger-shaped, narrow lake extending northward and in turn passing into a small stream that flows down from the plateau. Southward the peat area continues along the margin of the lake toward Newcastle Landing.

The stratigraphic features of the peat profile are comparatively simple. Broadly speaking the cross section consists of two layers. The upper layer is yellow-brown, poorly decomposed owing to a high water table, and is composed of matted, fibrous peat from interwoven rhizomes and roots of tule (*Scirpus* sp.), sedges (*Carex* sp.), and reeds (*Phragmites* sp.) In thickness the layer is about 8 to 9 feet and lies superimposed upon a basal layer of grayish-brown, finely-divided sedimentary peat. This, in turn, is underlain by gray sand at the depth of 43 feet below the present surface.

In morphological detail of structure the Mercer Slough peat profile presents some interesting facts.

The organic material at the bottom is firm, dark-brown, in a compacted and nearly dry condition, and sharply demarked from an overlying sheet of cream-colored volcanic ash at the 40 foot level. In its early postglacial history Lake Washington and vicinity must have received a large amount of pure volcanic ash which fell directly into the lake and brought to a close the accumulation of peat from the older vegetation growing at the shore. Pressed by the accumulation of later masses of peat above, the ash cover now measures a thickness from 3 to 8 inches and extends for miles, varying but slightly in thickness in different areas of peat. It was probably ejected from one of the craters of the Olympic Mountain range.

Three bands of soft, sedimentary peat are encountered with a moderate admixture of fibrous tule and reed material at depths of 14 and 17

feet, and between the 20 to 24 foot level. They alternate with diatomaceous sedimentary material that probably relates to conditions in which small forms of plankton life multiplied and developed more rapidly than the larger semi-aquatic marsh plants.

At a shallow depth of about 8 inches below the surface, the partly decomposed tule-reed peat is underlain by a thin band of sphagnum-moss peat. Islands of mosses appear to have followed a shrub stage, the remnants of which are a black woody debris, charred by fires and derived from ericaceous heaths such as *Ledum* sp. The band of moss peat is not extensive but forms lenses and in places overlies a thin layer of diatomaceous sedimentary peat. At depths of 7 and 9 feet below the surface an admixture of darker partly decomposed woody material is encountered. These variations are probably the result of local changes in water level. The plant remains are fresh-water forms, and throughout these changes the waters appear to have generally remained fresh rather than brackish or salty.

2. The Redmond peat profile

The Redmond record was obtained at the north end of Sammamish Lake in an area under cultivation in lettuce, located in T. 25 N., R. 5 E., section 2. The profile is similar to the one encountered at Mercer Slough and consists of two layers. The surface layer is partly fibrous, more or less decomposed reed-sedge peat over a band of diatomaceous sedimentary material below the surface 14 inches. Between the 3 and 10 foot levels the material is composed of fibrous yellowish-brown matted tule-reed peat, which contains at the 6 foot level a thin band of plant remains from hypnum mosses and at the 7 and 9 foot levels a quantity of partly decomposed woody fragments from deciduous shrubs, such as alder and birch.

The basal layer of finely divided sedimentary peat extends to a depth of 14 feet below the surface and corresponds in character to the plant remains which accumulated in Lake Washington. A bluish-gray find sand forms the underlying mineral substratum. An alternation of diatomaceous material is lacking and no sheet of volcanic ash was encountered. Although there is no interruption or change in the sequence such as that which marked the conditions at Lake Washington, it is inferred that the sedimentary peat at both localities is the same and was laid down under corresponding conditions. However, during its earlier period the valley floor of the Sammamish was being covered by deposits of sand and silt which the water carried at times of overflow. Eventually depressions formed in which water collected

and stood for long periods. The deeper water was filled with organic debris from hydrophilous vegetation until the mud flats became exposed, and reed and sedge marshes began to flourish in the drier portions of the basin. The bands of diatomaceous material at the shallow depth below the present surface as well as the woody material at the greater depths indicate that during the period of fibrous peat formation the depth of water changed and was accompanied by well-marked differences between plant communities, just as at Lake Washington.

3. The Renton type profile

At a point where the Duwamish and Cedar Rivers form a broad alluvial plain, deltas of sand occur at low levels along the eastern edge of the valley. They are bordered by an ill-defined swamp of shrubs and trees much of which is now under cultivation. One of the oldest agriculturally developed areas of shrub moor lies about 3 miles south of Renton in T. 23 N., R. 5 E., section 30. It may be reached from Seattle by railroads and electric car lines.

The peat layers of the Renton profile appear in a two-fold sequence and were observed in exposures along open ditches. Soundings obtained about 50 feet west of the main highway gave the following cross-section: The cultivated surface material consists of grayish-brown, crumbly, somewhat woody and silty sedge-reed muck, grading sharply into a brown, fibrous, compacted reed and sedge peat which contains rhizomes of *Equisetum* sp. The layer is usually found overlying a band of bluish-gray silt in which occur diatoms and root-channels stained yellow from iron salts. The mineral material rests upon a layer of brown woody-fibrous sedge-and-reed peat and contains the plant remains from species of tule and *Equisetum*. Irregularly distributed are logs of timber which may be driftwood or may indicate the occurrence of wooded islands in a wet marsh. The basal layer is essentially sedimentary peat material derived from aquatic plants and contains diatoms. The deposit is relatively shallow and usually about 5 feet thick. It rests on gray compact fine sand.

4. The Auburn peat profile

In the outer portion of the delta formed by White and Green Rivers, a deposit of peat occupies an isolated shallow water basin. It forms a divide with two divergent creeks, one flowing northward and the other southward. The area of peat is under cultivation, producing a variety of vegetables. It is located in T. 21 N., R. 4 E., section 23, about 1 mile southwest of Auburn near the western bank of the valley floor.

In stratigraphic features the profile resembles the Renton peat. The upper portion is generally well decomposed grayish-brown diatomaceous tule-reed muck and contains at the lower level woody fragments from conifers and deciduous shrubs. The basal portion of the profile consists of sedimentary diatomaceous peat and overlies a compact gray sand, somewhat clayey, containing occasionally ferruginous minerals. The deposit averages probably between 3 and 4 feet in thickness. The band of silty diatomaceous material corresponding in character to that near the surface at Renton, is missing or probably worked over and mixed by cultivation.

5. The Monroe type profile

Areas of peat occupy the valley floor along many stretches of the Snohomish River. The depth of these shrub and tree moors can not be inferred; it may be considerable. A main excavation in T. 27 N., R. 6 E., section 1 southeast of Monroe, afforded a considerable length of exposure for measurement indicating a three-fold sequence in the profile. The area is under cultivation, chiefly head lettuce being grown for eastern markets. The following features were noted in exposed cross sections averaging 3 to 4 feet in thickne-

The upper ten inches consist of cultivated dark grayish- ..own largely decomposed woody sedge-and-reed muck. This overlies a yellowish-brown compacted, coarsely fibrous and matted tule-reed peat containing flattened root-stocks of water lilies, arrow-grass, seeds of buck bean and others and a thin seam of sandy clay at the 18-inch level below the surface. The bed of mineral material usually directly overlies brown to dark-brown fibrous tule-reed peat, but a sharp separation from the latter is not always in evidence. A layer of woody peat with cedar and fir stumps *in situ* attains a thickness of 6 to 10 inches and forms a well defined stratum between levels of 26 to 32 inches below the surface. The basal layer is greenish-gray silty and clayey sedimentary peat in which are embedded rhizomes of several species of *Equisetum*, with roots of marsh plants extending downward into greenish sand below.

III

PROFILES OF PEATLANDS ON THE PLATEAUS

The plateaus comprise the greater part of the Puget Sound region. They are comparatively level to rolling uplands and contain depressions at irregular intervals which represent former basins of lakes and

ponds. The natural drainage of the peat areas of kettle-hole topography is usually very poor and the water holds as a rule only small amounts of mineral salts in solution which serve as plant food. The broader depressions are drained by small streamlets flowing in a tortuous course.

Although the peat areas are quite disconnected and miles apart, they have very much the same character of surface vegetation. The plant communities are northern in range and consist chiefly of a ground cover of sphagnum mosses with sundew and cranberry, clumps of ericaceous heaths such as swamp laurel, labrador tea, and a dwarf birch (*Betula glandulosa*). A detailed account of this type of vegetation has been given by Turesson (13) and Rigg (10). A domed surface or "highmoor" contour is only very slightly evident in one or more places.

The extinction of the small ponds in sphagnum moors is usually accomplished by filling with fine flocculent organic debris forming sedimentary peat. The material is made up of ubiquitous forms of plankton and fragments derived from the encroachment of a floating margin of semi-aquatic vegetation. The plant communities representing submerged or floating stages in the open water are dominated by pond weeds, bladderwort, water lily and water shield. The shore is occupied by purple marshlock (*Comarum palustre*) buck bean (*Menyanthes trifoliata*) and sedges whose strong fibrous rhizomes afford a frame-work for the support of mosses growing forward as floating islands. Near the rolling hills and ridges surrounding these depressions is the wooded portion of which the characteristic trees are cedar, fir, scrubby hemlock (*Tsuga heterophylla*) and occasionally Sitka spruce between moss-covered hummocks. They are fore-runners of the evergreen conifer forest.

The surface peat soils are mainly poorly decomposed spongy-fibrous sphagnum-moss peat. The results of the analyses reported by Rigg (11) and Thompson et al. (12) indicate that both the water and the moss peat of the bogs studied appear to be as leached and acid as the class of similar peat materials of the northeastern United States.

No agricultural use is made at present of these deposits and little or no study has been made of the differences of podsol-like characteristics developed in the underlying mineral substratum.

6. The Ronald type profile

The area occupied by the Ronald bog lies in T. 26 N., R. 4 E., section 8, of Snohomish County. This moss moor is not shown on the

Seattle topographic sheet. It is evidently a broad depression occupied by a three-layered accumulation of peat nearly 26 feet thick on a bed of drift sand and clay.

Examining the nature of the profile from the bottom upwards it appears that an outlet of the former lake was established relatively early. This is confirmed by the thin layer of sedimentary peat which averages only 3 feet in thickness. Diatomaceous material overlies the sandy substratum and an olive-brown colloidal detritus is found in the upper portion of the basal layer.

The course of development continued through a stage of plant succession no longer represented on the mainland at present. This is seen from the layer of yellow-brown poorly decomposed hypnum-moss peat. The plant remains accumulated to a thickness of 4 feet and overlie the lower layer of amorphous sedimentary peat.

From the stage of predominating hypnum mosses the area became subsequently a marsh inhabited by reeds, tule, and sedges. The peat material derived from them is coarsely fibrous, brown, matted to felty, and only partly decomposed. The thickness of the layer is nearly 16 feet and bears witness to accumulation over a considerable period of time.

A sheet of volcanic ash several inches thick found about 9 feet below the surface, denotes a critical stage in the history of the region. It does not appear, however, that the original flora had been wholly destroyed by the heavy fall of ash which covered the surface of the ancient marsh. The plant remains above the bed of volcanic ash indicate that the vegetation survived under the conditions following the volcanic activity. The soundings are not sufficient to indicate the direction of the wind-blown ash but the eruption was situated probably to the west on the coastal range of mountains.

Following the marsh stage, the course of development culminated in the invasion of sphagnum mosses. The surface layer of peat consists of over two feet of reddish-brown fibrous moss peat in which are embedded roots of heaths. A thin seam of black charred organic material separates the moss peat from the underlying sedge peat. The exact cause of the fire is difficult to conjecture. The replacement of the sedge marsh by the sphagum mosses denotes changes in the level and character of the ground water. The mosses succeeded in suppressing the marsh plants and established themselves in relatively recent times.

7. The Esperance type profile

The Esperance bog is an area of peat near the boundary line between Snohomish and King Counties and is located in T. 27 N., R. 4 E., section 31, south of the Ronald bog. It surrounds a small pond of open water.

The most striking feature of the profile is the complete absence of any layer of sedge or reed and tule peat. Floating mats of sphagnum mosses, supported by rhizomes of a few sedges and by the branches of ericaceous shrubs, have reached out to the open water. Test borings were made near the margin of the pond. They indicate that a nearly pure growth of sphagnum mosses, sinking down by continual growth, has filled the water basin with loose, soft and spongy-fibrous moss peat to a depth of nearly 20 feet. Methane gas was observed to escape from various levels below the surface. The moss peat grades more or less sharply into oozelike diatomaceous sedimentary peat 12 feet thick at the point examined. The mineral substratum varies from bluish-gray clay to gray sand.

The occurrence of a sheet of volcanic ash at a depth between the 28 and 29-foot level is of interest as indicating the former extent of the ash cover. The volcanic material is of the same color, composed of similar fine-grained minerals resembling crushed glass, and is seemingly related to the ejected material in peat profiles north and east of this locality.

8. The Hooven peat profile

The Hooven bog is another one of many typical "kettle hole" moss moors in the Puget Sound region. The peat area is shown on the Seattle topographic sheet, and lies about 2 miles southwest of Maltby in Snohomish County, in T. 27 N., R. 5 E., section 35. The general shape of the pond in the bog is circular. It has neither an inlet nor outlet. In its general aspects the zonal arrangement of the plant communities is very much like that described above; submerged and floating stages with many species of aquatic plants merge with the encroaching shore-line vegetation, and the zone of sphagnum mosses together with the ericaceous associates and clumps of shrubs continues into the boggy woodland of evergreens.

The maximum depth of the test borings exceeded 28 feet. The morphologic features of the two-layered water-logged profile bear the closest resemblance to the cross section of the Esperance bog. The upper layer is a relatively pure reddish to yellowish-brown spongy-

fibrous and poorly decomposed sphagnum-moss peat. The lower layer consists of sedimentary peat which contains numerous diatoms and a sheet of volcanic ash between the 23 and 24-foot level below the surface. The underlying mineral substratum is sand and clay.

9. The Cottage Lake type profile

The location, form, and dimensions of this area of peat are shown on the Seattle topographic sheet in T. 26 N., R. 6 E., section 17 of King County. It is drained by a small streamlet emptying into Sammamish Lake. A shallow excavation has been dug just west of the highway, making a section about 2 feet deep and over 50 feet square.

The excavation and additional soundings show that this portion of of the peat area consists of a four-layered profile. The surface layer is composed of 6 feet of brown fibrous sphagnum-moss peat penetrated by roots and stems of woody perennials. Alternating bands and thin streaks of dark partly disintegrated moss peat are of frequent occurrence and the material is somewhat more compact toward the lower level.

There appear to be no stumps except in a single layer of woody-fibrous peat which contains partly decayed logs of fallen and submerged timber between 6 and 7 feet below the surface.

Underlying the layer of woody-fibrous peat follows a brown to yellow-brown fibrous layer of tule-reed peat 8 feet thick which emits methane gas at different levels. In places the sounding instrument penetrates thin beds of woody material which represent the remains of alder thickets and ericaceous shrubs; they indicate temporary drier stages of the marsh.

A thin sheet of volcanic ash lies near the bottom of the tule-reed peat, about 15 feet below the surface.

The underlying basal layer consists of olive-green diatomaceous sedimentary peat. At a considerable distance below, approximately at the 25-foot level, appears a second sheet of volcanic ash overlying a firm olive-brown flocculated organic sediment. The bottom is clay and is reached at a depth of 41 feet.

10. Lake No. 12 peat profile

The typical occurrence of the four-layered sequence in the Cottage Lake peat profile may be observed also in the peat area bordering Lake No. 12 east of Auburn in T. 21 N., R. 7 E., section 7 of King County.

Soundings about 100 feet east of the western border of the peat area yielded complete sections for detailed comparison.

There are resemblances in the upper layer of sphagnum-moss peat and in the underlying woody material with its stumps of conifers which bear evidence of fire, and their later disappearance and burial by the invasion and establishment of sphagnum mosses.

From the 8 to the 21-foot level of the cross section is a massive layer of sedge-and-reed peat with beds of hypnum-moss peat near the 15 to 17 and the 18 to 20-foot levels. A thin sheet of ochreous-yellow mineral occurs in the fibrous sedge peat at the 14-foot level, which must have been washed in by the action of water. Over the top section of the mineral material sedimentary organic debris is embedded in fibrous plant remains derived from sedges.

The basal layer is sedimentary diatomaceous peat and underlying it is light gray, compact sandy clay.

11. Evans Creek type profile

This area of peat is a heath moor with an open growth of conifers. It lies southeast of Redmond in T. 25 N., R. 6 E., Section 22 of King County, and is traversed by Evans Creek which empties into the northern end of Sammamish Lake.

Test borings made south of the highway show that the cross section presents a three-fold sequence of peat layers. The upper layer is 6 feet thick. It consists of a thin cover of dark-brown largely decomposed sphagnum-moss peat containing dry leaves of heath shrubs, charred debris from occasional fires, and slender rootlets of the growing surface vegetation; this grades sharply into brown to yellow-brown, spongy-fibrous, more or less poorly decomposed moss peat in which water stands approximately 18 inches below the surface. Below the moss peat follows a layer of woody-fibrous dark-brown heath peat, 1½ to 2 feet thick, in which are embedded coarse fragments of woody material from conifers, and a large proportion of partly fibrous sedge peat. Obviously at some time before the sphagnum mosses established themselves, heaths such as Ledum, Kalmia, and islands of scrubby conifers, were growing upon a thin mat of sedges that had closed by encroachment a senescent lake. The basal layer is diatomaceous sedimentary peat underlain by coarse gray sand. The total thickness at the points sounded measures 13 to 15 feet. A close examination showed no evidence of the presence of seams or sheets of volcanic ash.

SUMMARY

1. In the Puget Sound region two different groups of peatland or moors can be distinguished. Both arise and develop from an initial aquatic vegetation, followed by marsh-plant communities; both may culminate in the coniferous climax forest of the region. In other respects, however, there is no parallelism between the two groups. The first group continues in so far as the marsh stage is concerned and may be succeeded by a mixed deciduous-shrub and conifer-tree growth. The second group deviates from the first one by the stage developing from the spreading of sphagnum mosses which eliminate and ultimately supplant both the marsh and shrub vegetation units.

2. Pedologically the areas of peat may be broadly divided into two groups and 7 types. In the first group are the relatively productive mesotrophic lowmoor peatlands which have fibrous or woody-fibrous reed-and-sedge peat at the surface. They occupy the broad valleys of streams in which temporary floods occur during the wet seasons favorable to a luxuriant growth of herbaceous grasses and sedges and ligneous deciduous-shrub vegetation. The peatlands are characterized by two- and three-layered limnogenic peat profiles. In the second group are the comparatively unproductive highly acid oligotrophic areas of peat which contain a surface layer of fibrous sphagnum moss peat in varying thicknesses. They occupy depressions upon rolling uplands into which water entered of necessity by rainfall and seepage and consequently remained deficient in the mineral salts that are so effective in the flood plain. The peat areas are moss-and-heath moors characterized by two-, three-, and four-layered, limnogenic peat profiles, having a high water table.

3. The deeper depressions show evenly distributed sheets of pure cream-colored volcanic ash which forms a well defined and sharply separated cover over the plant remains of the remoter period. The ash cover extends for miles and must have fallen directly upon the ancient lakes and marshes. It did not bring to a sudden close the vegetation of that period; the same variety of forms and the same succession of generations of plants appear to have continued in the open water basins and marshes.

The layer of volcanic ash seems to diminish in thickness in an eastward direction and suggests the presence of active volcanic vents along the western border of the Puget Sound Basin from which showers of erupted material were drifted by the action of prevailingly westerly winds. The data at hand are not sufficient to place in their proper

chronological order the sheets of volcanic ash recorded at different depths in the widely separated peat deposits.

4. No evidence has been obtained in the profile features of the Puget Sound peat areas to indicate a sinking of the land. The conditions appear to be favorable for assuming an appreciable re-elevation in geologically recent time.

LITERATURE CITED

1. BRETZ, J. H. *Glaciation of the Puget Sound region.* Wash. Geol. Surv. Bul. 8. 1913.
2. BYERS, H. G. *The water resources of Washington.* Wash. Geol. Surv. Bul. **1**, PartV: *1–11.* 1901.
3. DACHNOWSKI-STOKES, A. P. and WELLS, B. W. *The vegetation, stratigraphy and age of the "Open Land" peat area in Carteret County, North Carolina.* This JOURNAL **19**: *1–11.* 1929.
4. DACHNOWSKI-STOKES, A. P. *Peat profiles of the Everglades in Florida: the stratigraphic features of the "upper" Everglades and correlations with environmental changes.* This JOURNAL **20**: *89–107.* 1930.
5. DACHNOWSKI-STOKES, A. P. *Peat profile studies in Maine: The South Lubec "heath" in relation to sea level.* This JOURNAL **20**: *124–135.* 1930.
6. DACHNOWSKI-STOKES, A. P. *Peat profiles of the Delta Land of California.* Proc. and Papers Second Internat. Congress Soil Sci., U. S. S. R. 1930. In press.
7. KIMBALL, J. P. *Physiographic geology of the Puget Sound Basin.* Am. Geol. **19**: *225–237, 304–322.* 1897.
8. MANGUM, A. W. *Reconnaissance soil survey of the eastern part of the Puget Sound Basin, Washington.* Field Operations of the Bureau of Soils, U. S. Dept. of Agric. Eleventh Report (1909): *1517–1600.* 1912.
9. MARBUT, C. F. *A scheme for soil classification.* Proc. and Papers First Internat. Congress Soil Sci. **4**: *1–31.* 1927.
10. RIGG, G. B. *Some Sphagnum bogs of the north Pacific coast of America.* Ecology **6**: *260–278,* 1925.
11. RIGG, G. B., THOMPSON, T. G., LORAH, J. R., and WILLIAMS, K. T. *Dissolved gases in waters of some Puget Sound bogs.* Bot. Gaz. **84**: *264–278.* 1927.
12. THOMPSON, T. G., LORAH, J. R., and RIGG, G. B. *The acidity of the waters of some Puget Sound bogs.* Journ. Am. Chem. Soc. **49**: *2981–2988.* 1927.
13. TURESSON, G. Lysichiton camtschatcense (*L*) *Schott, and its behavior in sphagnum bogs.* Am. Journ. Bot. **41**: *189–209.* 1916.
14. VAN WINKLE, W. *Quality of the surface waters of Washington.* U. S. Geol. Survey Water-supply Paper **339**: 1914.
15. WILLIS, B., and SMITH, G. O. Tacoma Folio **54,** U. S. Geol. Survey, Geologic Atlas of the United States, 1899.

PALEONTOLOGY.—Trophocrinus, *a new Carboniferous crinoid genus.*[1]

EDWIN KIRK, U. S. Geological Survey.

Carboniferous crinoids of minute size have long been known but have not attracted the attention they deserve. It is hoped that with the present intensive study of micro-faunas a special effort will be made to discover and study these forms. In material kindly placed in my hands for study by Dr. G. H. GIRTY of the United States Geological Survey was found a crinoid showing unique structural modifications, which is here described as a new genus. In all 25 or more well-preserved specimens of the type species are available for study, comprising an unusually complete ontogenetic series. The specimens range in height from 0.75 millimeter to approximately 1.3 millimeters. There are smaller specimens, probably belonging to the species, but they can not be determined with certainty.

Trophocrinus, new genus

The orientation of the theca is based on the position of the largest, hydropore-bearing oral, which is posterior.

Basal elements three in number, the smallest unfused plate being the left anterior.

Radials five in number, varying considerably in width and somewhat in height. But one radial, the left anterior, has an arm facet. The outstanding structural peculiarity of the type species is an extraordinary hypertrophy of the left posterior and left anterior radials. The inner portions of these plates are produced upward, outward, and then inward to form a pouchlike chamber, opening toward the tegmen. Because of its close association with the single brachial appendage and by analogy with other echinoderms it is thought that this chamber may have served as a brood pouch. It will so be styled in this description. There is an associated crinoid with a single arm facet on the left anterior radial but without the brood pouch. This suggests the possibility that we have to deal with a sexually dimorphic type, but as this is obviously impossible of verification with fossil material the brood pouch is here held as one of the major distinguishing generic characters.

In common with many of the Carboniferous crinoids the plates of the theca are minutely pitted. In the case of *Trophocrinus* and some other Allagecrinidae these pits seem to have a more or less regular arrangement on the radials and to be connected with structures within the plates. When a radial plate is somewhat eroded a definite pattern is visible within the plate. In *Trophocrinus* as seen this is not as well shown as in some related forms, possibly owing to differences in erosion. In general within the plate may be seen a median series of vertical light and dark lines, running lengthwise of the plate. To either side are series of similar lines arranged horizontally and normal to the common suture between adjacent radials. As seen under various lighting conditions and immersed in different clearing media it would appear that there are series of tubules within the body of the plate, possibly

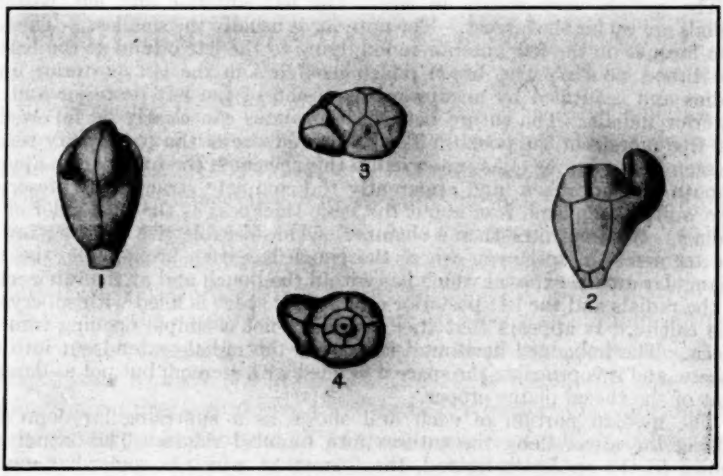
[1] Published by permission of the Director of the U. S. Geological Survey. Received April 30, 1930.

connecting with the external pits. Their general similarity to hydrospire-folds and pore-rhombs is suggestive. Isolated plates examined on both sides show no signs of folds in the stereom, and whatever these structures are they seem to lie within the substance of the plate proper.

Of the five orals the posterior is the largest and has a sharply defined pimple near the apex, which is undoubtedly the site of the hydropore. The posterior oral as in *Allagecrinus* meets only the right and left anterior orals at the center of the tegmen. The right and left posterior orals are much smaller and do not reach the center.

Trophocrinus is referred to the family Allagecrinidae.

The genotype is *Trophocrinus tumidus*, new species, from the Sycamore limestone (Mississippian) of Oklahoma.



Trophocrinus tumidus, n. gen., n. sp.

Figure 1. × 20. Viewed from left posterior interradius.
Figure 2. × 18. Same specimen. Anterior view.
Figure 3. × 18. Same specimen. Tegminal view.
Figure 4. × 18. Same specimen. Basal view.

Trophocrinus tumidus, new species

Figs. 1–4

Owing to the small size of the crinoids, details of structure can only be worked out and verified by the examination of a number of specimens. The individual here illustrated, one of the cotypes, is one of the largest and the only one in which the remarkable pouchlike structure is completely preserved. The magnification of Figure 1 is approximately 20 x, while that of the other three figures is approximately 18 x. The drawings were made by using a camera lucida attached to a binocular microscope and although semi-diagrammatic give an excellent idea of the crinoid.

The specimen here figured has a height to the apex of the orals of slightly more than 1 millimeter and to the crest of the brood pouch of 1.2 millimeters. The posterior-anterior diameter is 0.6 millimeter, and the maximum diameter from the right anterior radius to the left posterior interradius is 0.9 millimeter. This specimen would appear to be of average adult size, comparing it with a dozen of the largest specimens found.

The theca is subpyriform in shape and usually is somewhat asymmetrical in outline, not considering the great asymmetry introduced by the brood pouch. The relative proportions of the cup and tegmen may readily be seen in the figures.

All the interbasal sutures are seldom shown in a single specimen. Examination of a number of specimens, however, proves that there are three basal elements and the small unfused basal is the left anterior.

The radials vary widely in size. The left anterior and left posterior radials are by far the largest. The anterior is usually the smallest. The only arm facet is on the left anterior radial, lying to the left of and at the base of the brood pouch. The brood pouch itself lies in the left posterior interradius and is formed by an upward extension of the left posterior and left anterior radials. The suture between the plates can clearly be followed to the free margin of the pouch. The shape and size of the pouch may readily be seen in the figures. As preserved in this specimen the free margin appears smooth and unbroken, and apparently the complete structure is preserved. The wall of the pouch is of about the same thickness as the remainder of the radials. It constitutes then a chamber of considerable size opening toward the tegmen. In specimens where the pouch has been broken off the subtriangular area is exposed which lies within the pouch and at the intersection of the radials and the left posterior oral. This space is filled with subcrystalline calcite. It appears that this space was not a simple opening into the theca. The imbedded horizontal tubules of the radials extend out into this calcite, and it is probable the space was filled with stereom but not as dense as that of the thecal plates proper.

The median portion of each oral shows as a subtriangular depression raising the areas along the sutures into rounded ridges. This is not well shown in the specimen figured, the tegmen of which is somewhat eroded. Near the apex of the largest oral is a well defined round protuberance, which undoubtedly marks the site of the hydropore.

Horizon and locality.—The specimens of *Trophocrinus tumidus*, together with other *Allagecrinus*-like crinoids and a minute *Catillocrinus*, were found in material collected by G. H. GIRTY, C. L. COOPER, and others in a shale immediately below the main limestone ledge of the Sycamore limestone in a railroad cut south of Ada, Okla., in sec. 27, T. 3 N., R. 6 E.